Long Overdue Cerenkov Counter Documentation

To: E766/E690 Collaboration
From: David Christian

1) Design.

a) Cerenkov Radiation Formulae

$$\cos\theta = 1/\beta n \; ; \; \cos\theta_{max} = 1/n$$

$$P_{th} = (m/n)/\sin\theta_{max} \; ; \; P_{th} \approx m/\theta_{max}$$

(n = index of refraction ; m = mass of radiating particle)
(P_{th} = threshold momentum)

$$dN/d\nu = (2\pi L/137c)\sin^2\theta$$

N = number of photons
L = length of radiator
Note: n (and therefore θ) is a function of ν

If n is constant then

$$N = N_0 L \sin^2\theta \approx N_0 L \theta^2$$

In this approximation the quantities needed for Cerenkov analysis are $\sin\theta$ and $\sin^2\theta$. The most convenient expression is:

$$\sin^2\theta = (1 - P_{th}^2/p^2)\sin^2\theta_{max}$$

b) Choice of Radiator

The goal is to identify as many particles by Cerenkov radiation as possible. Time of flight identification is "easy" to about 1 GeV/c and "possible" to about 2 GeV/c (given the length of our spectrometer). It follows that one would like to build a Cerenkov counter in which pions with momentum above 1-2 GeV/c would radiate light. Aerogel has a pion threshold of 600 MeV/c and various pressurized gases may be used to yield a pion threshold between 1 and 2 GeV/c, but I know of no gas

with a high enough index of refraction at atmospheric pressure to yield a pion threshold below 2 GeV/c. It is therefore necessary to trade off particle identification against multiple scattering and interactions in the counter. If BNL E766 were the end of the line for this spectrometer, the optimal choice would be a high pressure gas Cerenkov counter; however, for E690 it is clear that the additional material that the pressure vessel and pressurized gas would represent would not be acceptable. There are a variety of gases whose index of refraction is such that pions begin to radiate light if their momentum is greater than approximately 2.5 GeV/c. A short list is given below:

Radiator	Index of Refraction	$Theta_{max}$	Pion Threshold (GeV/c)	Absorption Edge (A)
Freon 114 $C_2Cl_2F_4$	1.0015	54 mrad	2.57	2200
Isobutane isoC_4H_{10}	1.0015	55 mrad	2.55	1700
Perfluorobutane C_4F_{10}	1.0015	55 mrad	2.55	
Freon 116 C_2F_6	1.0008	40 mrad	3.50	
Ethane C_2H_6	1.0009	42 mrad	3.30	1600
Perfluoropentane C_5F_{12}	1.0017	59 mrad	2.37	
Perfluorohexane C_6F_{14}	1.0020	63 mrad	2.24	

In all of these cases, the index of refraction is essentially constant for visible and near ultraviolet light, but gets larger fairly quickly for light with wavelengths shorter than approximately 2500 angstroms. For short enough wavelengths no light is transmitted through the gas. Freon 114 is the worst of the gases listed in that it absorbs light with longer wavelengths than any other. The simple fluorinated hydrocarbons are generally significantly less dispersive than the analogous hydrocarbons and transmit light of shorter wavelength. On the other hand, since they contain fluorine they are significantly heavier and have significantly shorter radiation lengths than the hydrocarbons. Freon 114 contains chlorine and is the heaviest of all the gases listed. The hydrocarbons are flammable whereas the Freons are not. The hydrocarbons are all quite inexpensive, whereas the price of the Freons varies considerably. Of the gases listed above, Freon 114 and Freon 116 are used as refrigerants and are not too expensive, the other three are "exotic" and quite expensive. All of the gases listed have relatively high boiling points which means that care must be taken to see that they do not condense. In fact perfluorohexane's boiling point is approximately 60 degrees centigrade. The numbers listed for perfluorohexane are for gas at 61 degrees centigrade.

Freon 114 was used as the Cerenkov radiator for E766. The plan is to switch to isobutane for E690.

c) Length of Radiator; Mirror Sizes

The formula listed above for the number of photons produced usually is reinterpreted as an expression for the number of photoelectrons detected. In this case, N_0 includes all losses of photons as well as all of the constants in the expression for the number of photons produced. "Experience" shows that if L is given in cm, then for Freon 114 $N_0=75$ is "good". This implies that in order to require N=15 for $\beta=1$, the radiator must be approximately 68.6 cm=27 inches long. If isobutane were used instead of Freon 114, the same optics and phototubes would yield a greater value for N_0 and the radiator could be slightly shorter.

A $\beta=1$ particle radiating in 27" of either isobutane or Freon 114 produces a 2.92" diameter spot at the mirror. This provides a natural scale for the size of the mirrors; one wants as many mirrors as possible in the central region of the counter where there may be many radiating particles in an event, but it doesn't make sense to make the mirrors small compared to the spot size. The requirement that each mirror focus light on one and only one phototube provides an even tighter constraint on the mirror size. For our geometry, the best possible focus for the cells in the middle of the counter yields a "spot" (by which I mean the envelop of light from all possible particles) which is approximately five inches in diameter.

The (projected) mirror size was chosen to be six inches square for the central portion of the counter and twelve inches square for the outer portion of the counter. The counter as built has approximately 20" of radiator in front of the central mirrors.

d) Optical Design

The basic idea was: For each mirror, consider all possible radiating particles, reverse the direction of each ray of Cerenkov light and trace it back in a straight line to the z of the center of the LH2 target. Then consider an "object" located at the z of the center of the LH2 target whose extent in x and y is the boundary of the set of points found by tracing the Cerenkov rays. One gets essentially the same "object" for every mirror. If the mirrors are designed to image this "object" all possible Cerenkov light will also be imaged.

Most multicell Cerenkov counters have the mirrors mounted so that they may be aligned by moving and or rotating the mirrors individually after the counter is assembled. I could not think of any such mounting scheme which would be lightweight and easy to use with 96 mirrors. Therefore, the counter was designed and built with two mosaics of mirrors in an arrowhead configuration as shown in figure 1. The mirrors

were mounted permanently; alignment in place was accomplished by moving the phototubes, which were clamped into position on oversized holes in the gas box rather than installed in a fixed position. Each phototube was separately oriented by a machined aluminum wedge so that its front face was held perpendicular to the nominal reflected central ray. The mirrors were mounted on two planes with the normal through the center of every mirror on a plane perpendicular to that plane. The phototubes were placed at the top and bottom of the counter rather than on the sides so that they could be as close to the mirrors as possible. The requirement that the tubes be close to the mirrors also meant that Cerenkov light was incident on the mirrors at large angles with respect to normal incidence. This in turn meant that the best light collection would have been achieved if the mirrors had been ellipsoidal, with one focus at the center of the hydrogen target and the other at the phototube. Toroidal mirrors were actually made, since they provided a reasonable approximation to ellipsoids and the molds were much easier to machine.

The shape of the each toroidal mirror was completely determined by the position of the mirror, the requirement that an "object" centered on the target be imaged, and the position chosen for its image. The ideal radii of curvature of each mirror are given by:

$$R_h = (2/Cos\phi)(sL/s+L) \qquad R_v = (2Cos\phi)(sL/s+L)$$

ϕ = The angle of incidence with respect to normal incidence.
s = The distance from the mirror to the focus.
L = The distance from the center of the target to the mirror.
R_v = The radius of curvature in the plane in which the central ray is at normal incidence.
R_h = The radius of curvature in the "scattering plane", that is, the plane containing ϕ.

The angle between the "scattering plane" and vertical determined the orientation of the edges of the rectangular mirrors with respect to the two toroidal axes (see figure 2). Rather than optimize each mirror for its position in the array, six different groups of mirrors were defined (see figure 3) each with its own values of R_h and R_v. Within each group (except group 6), four different orientations with respect to R_h and R_v were defined (two orientations were defined for group 6). The result was 24 different types of mirrors. Four mirrors of each type were used; two on the upper mirror plane and two on the lower mirror plane.

2) Physical Description

The Cerenkov counter used in BNL E766 contained ninety six concave toroidal mirrors and an equal number of two inch diameter phototubes (EMI 9954). Seven stage "Knapp" bases were used and all of the tubes were run at 2300 volts. The discriminator thresholds were all set low

enough to be fully efficient for single photoelectron signals. The mirror array covered an area 96 inches horizontally by 64.75 inches vertically and approximately matched the acceptance of chamber six. There were three sizes of mirrors used: 6" x (6/sin(60))"; 12" x (12/sin(60))"; and 12" x 9.66". The small mirrors were slumped out of 1 mm thick glass; the two larger sizes were slumped out of 1.5 mm thick glass. The mirror specifications are listed below

Mirror Type	R_h	R_v (All in inches)	Size	Orientation (Degrees)
1	53.05	38.15	6x6/Sin(60)	5.15
				-5.15
				15.14
				-15.14
2	47.54	32.32	6x6/Sin(60)	4.67
				-4.67
				13.77
				-13.77
3	42.60	27.33	6x6/Sin(60)	4.27
				-4.27
				12.62
				-12.62
4	49.45	29.85	6x6/Sin(60)	3.93
				-3.93
				11.65
				-11.65
5	42.79	24.00	12x9.66	7.15
				-7.15
				22.09
				-22.09
			12x12/Sin(60)	22.09
				-22.09
6	53.75	35.35	12x12/Sin(60)	27.22
				-27.22

The mirror blanks were made by United Lens Co. of Southbridge, Mass. Concave stainless steel molds were machined using a numerically controlled milling machine and then stoned by hand to achieve a smooth surface. A circular piece of glass was placed onto a mold and heated in an evacuated oven until it slumped into the mold. The temperature was then reduced according to an annealing schedule which took approximately fifteen hours (The time was longer for the big mirrors which were slumped into more massive molds than the small mirrors). The blanks were cut to size later as follows: A thin rubber sheet was placed into the mold and the curved blank placed on top of it. The mold was positioned on the table of a milling machine and its orientation with respect to the axes of motion of the table fixed. A scratch was

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made in the glass using a glass cutter constrained by a fixture to move only in the "y" direction of the table. The table was moved in the x direction and a second scratch made. Then the mold was rotated by 90 degrees and two more scratches made. After the glass was broken along the scratches the blanks were within +0/-.010" of the specified dimensions. The care taken in annealing the glass assured that the curvature was uniform over the entire blank.

A mirror surface was applied to the glass blanks by the Acton Research Corp. of Acton, Mass. The mirror surface consisted of a layer of Aluminum and an overcoat of magnesium fluoride. The thicknesses were chosen to maximize reflectance for light with a wavelength of 1700 angstroms and an angle of incidence of 35 degrees. A witness blank (microscope slide) was coated along with every batch of mirrors. The reflectivity of the witness blanks measured at 1700 angstroms and 35 degrees all exceeded 84%.

The mirror support panels were made by the General Veneer Manufacturing Co. of South Gate, California (see figure 4). They were made from one inch thick 1/8" cell 1.8 pound per cubic foot Dupont "Nomex" resin soaked paper honeycomb with .005" thick woven carbon fiber skins (4133 square weave) with just enough resin to wet the fibers and bond them to the core. A witness sample was subjected to destructive testing to insure that proper bonding had taken place. The witness sample composite of carbon fibers, resins, and paper honeycomb weighed 0.303 +/- 0.002 pounds per square foot. Three of the four sides of the panels were finished with two inch wide polyurethane foam core closeouts which could be drilled through. Aluminum angle fixtures were attached to the closeouts on each end and used to hold the mirror arrays in place.

The mirrors were mounted on the support panels permanently using a very small dab of 3M quick setting structural epoxy. The procedure was as follows: The mirror tiling pattern was drawn on the honeycomb panel using a red marker. The panel was placed on the floor near a wall and shimmed to level. A floodlamp was hung on the wall to simulate a source of light at the center of the LH2 target and a wooden fixture holding forty eight bulls-eyes placed over the honeycomb panel so that each bulls-eye was at the nominal focus of a mirror (see figure 5). The mirrors were glued in position by painting a dab of glue onto the honeycomb panel, laying the mirror down and adjusting it until the image of the floodlamp focussed properly on the correct bulls-eye and watching it until the glue hardened to make sure that it didn't move. The result was two mirror arrays in which the relative positions of forty eight mirrors was very well known and simple to describe; the mirror edges formed straight lines and there were no large cracks.

Straight cones were used to collect that fraction of the light reflected by the mirrors which could not be made to focus directly onto the

phototubes. The reflecting cones were made of .005" mylar which was coated by Acton Research with a layer of SiO (approximately 500 angstroms thick) followed by an opaque layer of aluminum and a magnesium fluoride overcoat optimized for reflection of 1700 angstrom light incident at 70 degrees from normal. The reflectance of a witness slide was measured for each coating run using 1700 angstrom light at 70 degrees. All of the witness slides had at least 80% reflectance. The coated mylar sheets were glued with five minute epoxy into machined aluminum cones. Each aluminum cone had steps and grooves machined in it to accommodate a phototube, o rings, and magnetic shields (see figure 6). If reflecting cones had been made in their final shape (either from plastic or glass) it would not have been possible to apply a good UV reflective surface since there would have been no way to hold an appropriate number of magnesium fluoride crystals in position to be evaporated onto the inside of the cone. The machined aluminum cones were glued to aluminum wedges and clamped onto the gas box. The wedges were machined so that a ray drawn from the center of the LH2 target to the mirror would be reflected towards the phototube parallel to the long axis of the tube. The wedge specifications for one quadrant are listed below:

Wedge Position on outside of 3/4" thick Al plate (inches)		Wedge Angle (degrees)		Wedge Rotation (with respect to x of the plate) (degrees)
x(long dir.)	y(short dir.)			
3.65	3.60	5.2	(Mirror type 1)	75
10.94	3.60	6.4		51
18.23	3.60	8.4		37
25.52	3.60	10.6		28
35.87	7.15	13.5	(Mirror type 6)	16
50.22	7.15	18.3		11
3.53	10.59	2.8	(Mirror type 2)	62
10.59	10.59	4.6		32
17.66	10.59	6.9		20
24.72	10.59	9.4		15
3.42	17.16	1.3	(Mirror type 3)	0
10.27	17.16	3.8		0
17.12	17.16	6.3		0
23.97	17.16	8.8		0
33.73	20.30	12.3	(Mirror type 5)	-5
47.23	20.30	17.0		-4
3.48	23.66	2.6	(Mirror type 4)	-62
10.45	23.66	4.3		-32
17.42	23.66	6.5		-20
24.39	23.66	8.8		-15
6.73	30.94	5.4	(Mirror type 5)	-64
20.20	30.94	8.6		-34
33.66	30.94	12.6		-22
47.13	30.94	16.8		-16

The gas box was constructed from Aluminum plates and angles welded together. Chamber six mounted on the front on the Cerenkov counter. The front window used for E766 was .010" thick black vinyl with aluminum bonded to one side. The window was mounted on the back of the chamber six assembly. The back window used for E766 was made from welded aluminum sheet metal.

3) Analysis Constants

a) Alignment Constants

The mirror positions were well known with respect to one another within a mirror plane. The only alignment constants which were needed were those which described the position and orientation of the two planes of mirrors. These were determined using tracks which shared light between adjacent mirrors to locate the mirror edges. Currently, these constants are defined in SUBROUTINE TPC0MP and are:

O(1-3) : (x,y,z) of the point between mirrors 13 and 17 closest to mirrors 61 and 65 (z relative to the rear hodoscope).
O(4-6) : (x,y,z) of the point between mirrors 61 and 65 closest to mirrors 13 and 17 (z relative to the rear hodoscope).
E1(1-3): The x unit vector of the upper plane.
E1(4-6): The x unit vector of the lower plane.
E2(1-3): The y unit vector of the upper plane.
E2(4-6): The y unit vector of the lower plane.
PN(1-3): The unit vector normal to the upper plane.
PN(4-6): The unit vector normal to the lower plane.

b) ADC constants

The measure of light intensity which was used was obtained from the measured ADC value by subtracting the pedestal and dividing by a number corresponding to the light yield of a $\beta=1$ track. In addition, I have derived constants which may be used to convert the scaled ADC to an estimate of the number of photoelectrons observed. The procedures used to establish these constants are described below. I have not yet established any constants for the proton data, but I promise to do so as soon as I finish writing this memo!

4) Performance

Events from approximately ninety np runs with a K^0 with measured mass within four MeV of the nominal K^0 mass were selected. If the K^0 could have been a Λ or a γ it was discarded. Daughter pions with momentum greater than the observed pion threshold of 2.57 GeV/c were projected into the Cerenkov counter. Those tracks which were predicted

to radiate light on more than one mirror, or which shared a mirror with one or more other tracks, were discarded. The remaining tracks were used to accumulate ten ADC distributions for each mirror; each one for ten bins of $(1-6.6/p^2)$ $(6.6 = 2.57^2)$. If there were no dispersion in the Freon 114 and no systematic losses of light which depended on momentum, then the mean ADC value in each bin would have been equal to the mean value of $(1-6.6/p^2)$ in the bin. This was not the case; but it was found that, with the exception of the sixteen largest mirrors, the mean values for all mirrors followed the same function of momentum (See figure 7). When tracks which intersected one of the sixteen largest mirrors within four inches of the vertical edge closest to the center of the counter were excluded, the mean ADC values for these mirrors also followed the same form.

The expression for ADC as a function of momentum was first established for the central mirrors, and then used to calculate the ADC gain constants for all of the mirrors. In this step events were used in which a cell was on with exactly one track pointing to it, and that track had $(1-6.6/p^2) > 0.4$. The calculation was done using a group of runs numbered between 1422 and 1439 and repeated using a group of runs numbered between 1741 and 1760. The gain constants derived using the second group of runs were uniformly 3-5% higher than those derived using the first group of run. An average of the two numbers was used in all subsequent analysis.

When the response of large mirrors of "rows" 5 and 6 (see below) was plotted separately for tracks hitting within two inches of the inner edge and for tracks hitting between two and four inches of the inner edge, they too were found to follow approximately the same function of momentum, but with lower ADC values than the outer eight inches of the same mirrors. This reduced response is probably due to astigmatic smearing of the image in the horizontal plane. The mirrors actually focus better in the horizontal plane than they do in the vertical plane, but since tracks bend in the horizontal plane the image quality is more important in the horizontal than in the vertical plane. This effect would have been minimized if a number of small mirrors had been used in place of each of the large mirrors. It may be possible to partially compensate for this effect in the future by adjusting the position of the corresponding phototubes slightly.

For the central mirrors it was possible to establish (with fairly large statistical errors) the relationship between ADC value and the corresponding number of photoelectrons detected. Outside of the central mirrors there were not enough tracks in the sample of "good pions" to make reliable mirror by mirror estimates of the number of photoelectrons detected. Therefore, seven groups of similar mirrors were defined, and the relationship between ADC and number of photoelectrons was determined for each group. The mirrors in each group are listed below (see also figure 8).

Group	Mirrors in Group
1	1,5,9,13,17,21,25,29,49,53,57,61,65,69,73,77
2	2,6,10,14,18,22,26,30,50,54,58,62,66,70,74,78
3	3,7,11,15,19,23,27,31,51,55,59,63,67,71,75,79
4	4,8,12,16,20,24,28,32,52,56,60,64,68,72,76,80
5	33,36,43,46,81,84,91,94
6	34,37,44,47,82,85,92,95
7	35,38,39,40,41,42,45,48,83,86,87,88,89,90,93,96

Two methods were used to estimate the number of photoelectrons. The first method used only the fact that since some care had been taken to insure that the discriminators were fully efficient for detecting one photoelectron signals, then (Poisson statistics) the probability of seeing nothing was simply:

$P(0) = e^{-\langle x \rangle}$ with $\langle x \rangle$ = the average number of photoelectrons. Thus, $\langle x \rangle = -\ln(\text{inefficiency})$

The range $0.2 < (1-6.6/p^2) < 0.3$ was used for this calculation. All seven groups of mirrors had a significant number of tracks in this range and the inefficiency was 20-40% for all groups, which insured that the error on the estimate of the inefficiency was not too large and that the inefficiency was not dominated by the small fraction of the tracks which did not really come from K^0 decay. The number of photoelectrons expected for $\beta=1$ was estimated by dividing by the average ADC value in the $(1-6.6/p^2)$ band used.

The second method was to accumulate ADC distributions for tracks in ten bands of $(1-6.6/p^2)$ and then fit these as Poisson distributions. Each band yielded an estimate of the number of photoelectrons in that band, which was extrapolated to $\beta=1$ by dividing by the fit value of the mean ADC in the band. The second method was more sensitive to the width of the $(1-6.6/p^2)$ band than the first, since the distribution was at best really a superposition of Poisson distributions, each with a slightly different mean value. This effect increased the width of the distributions and therefore lowered the estimates of the mean values in terms of a number of photoelectrons. The second method was also more sensitive to phototube and ADC nonlinearities, to gain shifts with time, and (when signals from many mirrors were added together to yield adequate statistics) to small errors in the ADC gain constants, since all of these errors tended to increase the width of the distributions while having less effect on the means. All of these effects would tend to decrease the estimate of the number of photoelectrons made using the second method. The first method was sensitive to kaon and proton contamination in the track sample, and more sensitive than the second method to scintillation light, to phototube noise, and to accidentals. Kaon and proton

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contamination would decrease the estimate of the number of photoelectrons, while all sources of spurious signals would increase the estimate of the number of photoelectrons. Only tracks for which the appropriate phototube was either off or had a TDC value within a 33 bin wide "in time" range were used. This meant that outside of the middle mirrors, there were essentially no accidentals. A study of pions (from K^0 decay) with momentum in the range 1.6 - 2.4 GeV/c showed no evidence of scintillation light.

Group	Number of Photoelectrons for $\beta=1$	
	Method #1	Method #2
1	13.3	12.7
2	17.5	18.8
3	21.3	20.4
4	21.8	19.3
5	*14.2	12.5* (Excluding the
6	*16.8	17.0* ''inner'' 4")
7	17.1	14.3
Mirror #13	11.8	12.6
Mirror #17	12.3	10.4 (All low
Mirror #61	15.7	8.9 Statistics)
Mirror #65	9.5	11.4

5) Particle Identification Procedure

   a) Predictions

Each track with momentum at least 2.57 GeV/c is projected in a straight line from the rear hodoscope until it passes through a Cerenkov mirror. The total amount of light expected and the Sine of the Cerenkov angle are computed assuming first that the particle was a pion, then a kaon, and then a proton. The amount of light expected and $\sin\theta$ are computed using the function of $(1-p_{th}^2/p^2)$ described above. Finally the fraction of the predicted light expected on up to four mirrors is calculated for each of the three particle hypotheses. This is done by projecting the mirror boundaries onto a plane perpendicular to the particle direction and computing the sharing in this plane. In this plane the spot of Cerenkov light is circular and the light intensity in the spot easy to compute, since the number of photons emitted per length of radiator is constant. This calculation is further simplified by approximating the projected mirror boundaries by lines crossing one another at right angles. This approximation allows the calculation of how much light to expect on each mirror to be made using one lookup table. The predictions are stored in COMMON /CANL/.

The following complications are included in the calculation of how much light to expect:

1) No particle is predicted to hit a mirror if the recorded TDC value for that mirror is outside of a 33 bin wide window.

2) Light which falls on the crack at y=0 is not included in the amount expected on any mirror.

3) The prediction of how much light to expect for the largest 16 mirrors ("rows" 5 & 6) is reduced by 50% for row 5 and 80% for row 6 if the track hits within two inches of the inner vertical edge of the mirror (ABS(XM) between 22" and 26"). The prediction is reduced by 30% for row 5 and 40% for row 6 if the track hits between two and four edges of the inner vertical edge (ABS(XM) between 26" and 28").

b) Comparison with Data

I have written a group of subroutines to do Cerenkov particle identification based on a comparison of the predictions described above with the observed ADC values. It produces the following output:

```
      COMMON/CEROUT/IDCO(15),QPI(15),QK(15),QP(15),CL(3,15),
     X NSLIST,LISTSH(10,10)
      LOGICAL QPI,QK,QP
C
C--> IDCO(TRACK #) = -2 ==> TRACK HITS ONE OR MORE MIRRORS WHICH ARE
C                           ON & SHARED BY OTHER UNIDENTIFIED TRACKS.
C                   -1 ==> NO CERENKOV INFORMATION (EG P LT 2.57)
C                    1 ==> GOOD IDENTIFICATION (AT LEAST ONE
C                           HYPOTHESIS HAS BEEN RULED OUT)
C                    2 ==> INCONCLUSIVE INFO (ALL IDS POSSIBLE)
C                    4 ==> INCONSISTENT INFO (SOME IDS MAY BE
C                           RULED OUT)
C
C--> QPI(TRACK #) = .TRUE. IF CONSISTENT WITH PION
C    QK(TRACK #) = .TRUE. IF CONSISTENT WITH KAON
C    QP(TRACK #) = .TRUE. IF CONSISTENT WITH PROTON
C--> QPI,QK,QP MAY BE SET = .FALSE. IF IDCO IS 1 OR 4.
C
C--> CL(IH,TRACK #) = CONFIDENCE LEVEL FOR HYPOTHESIS 1-3 (PI,K,P)
C-->   CL IS LOADED IF IDCO(TRACK #) = 1,2, OR 4... IT MAY BE USED
C    TO REDEFINE THE CUTS WHICH DETERMINE THE VALUE OF IDCO.
C
C--> NSLIST = THE NUMBER OF LISTS OF TRACKS WHICH SHARE A MIRROR
C             WHICH IS ON...(AT LEAST ONE TRACK IN THE LIST
C             RADIATES.)
C--> NOTE: MORE THAN ONE LIST MAY CONTAIN EXACTLY THE SAME TRACKS.
C--> NSLIST MAY BE SET =11, BUT A MAX. OF 10 LISTS ARE STORED.
C
C-->LISTSH(1,LIST #) = MIRROR # WHICH IS ON AND SHARED BY UNIDENTIFIED
C                      TRACKS.
C-->LISTSH(2,LIST #) = # OF TRACKS IN LIST (SET = 9 IF MORE THAN 8
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C                         TRACKS SHOULD BE INCLUDED IN THE LIST.)
C    LISTSH(3-N,LIST #) = LIST OF TRACKS (UP TO 8 TRACKS)
```

Most identifications are done one track at a time, using mirrors which are off or unshared. A count of the number of hits on each mirror is made assuming that all tracks with momentum above 2.57 GeV/c are pions. If a track is unambiguously identified (IDC0=1) as "not radiating", then it is removed from the list of hits on the mirrors it would have illuminated if it had been a pion. If a track is unambiguously identified as a "radiating NOT PION", then the hit list is revised using the kaon hypothesis if the track could have been a kaon, or the proton hypothesis if it is a definitely identified proton. If an identified "radiating" track is predicted to contribute an amount of light to a mirror which is shared, and the predicted amount of light is "small" compared to the amount of light observed on that mirror, then the number of hits on the mirror is reduced by one, the amount of light predicted is subtracted from the amount observed, and the difference is used to try to identify other tracks. "Small" is defined in this context by the criterion that the (Poisson) probability of seeing the amount of light observed given the amount predicted for the identified track is less than .001.

Confidence levels are computed assuming Poisson statistics. If no more light is observed than was predicted for a given particle type hypothesis, the confidence level is defined as the probability of seeing no more light than was observed. If the amount of light observed was greater than the amount predicted, then the confidence level is the probability of seeing at least as much light as was observed.

Currently, a confidence level of .003 is required to call an hypothesis "acceptable". This means that no track is called "not radiating" until the number of photoelectrons expected exceeds 5.8. If two hypotheses are possible (for example if the track is above kaon threshold and the amount of light observed is between what is expected for a kaon and what is expected for a pion) then the less probable hypothesis is ruled out only if its confidence level is less than .003 and the confidence level for the more probable hypothesis is at least .1.

If exactly two unidentified tracks (both above pion threshold) share a lit mirror or group of lit mirrors after all possible single track identifications have been made, then an attempt is made to identify both tracks jointly. The same confidence level criteria described above are imposed. Only if no pair of particle type hypotheses is consistent with the amount of light seen, or if at least one of the pair can be unambiguously identified is any identification made.

Tracks above pion threshold which remain unidentified after this step and hit (pion hypothesis) a mirror which is on and shared only by other unidentified tracks are included in lists of tracks at least one of which must have radiated.

List of Figures

Fig. 21. Cerenkov counter optics, side view.

Figure 1 — Thanks to Mike Church

TYPICAL "6"" MIRROR

6"

6"/sin(60°)

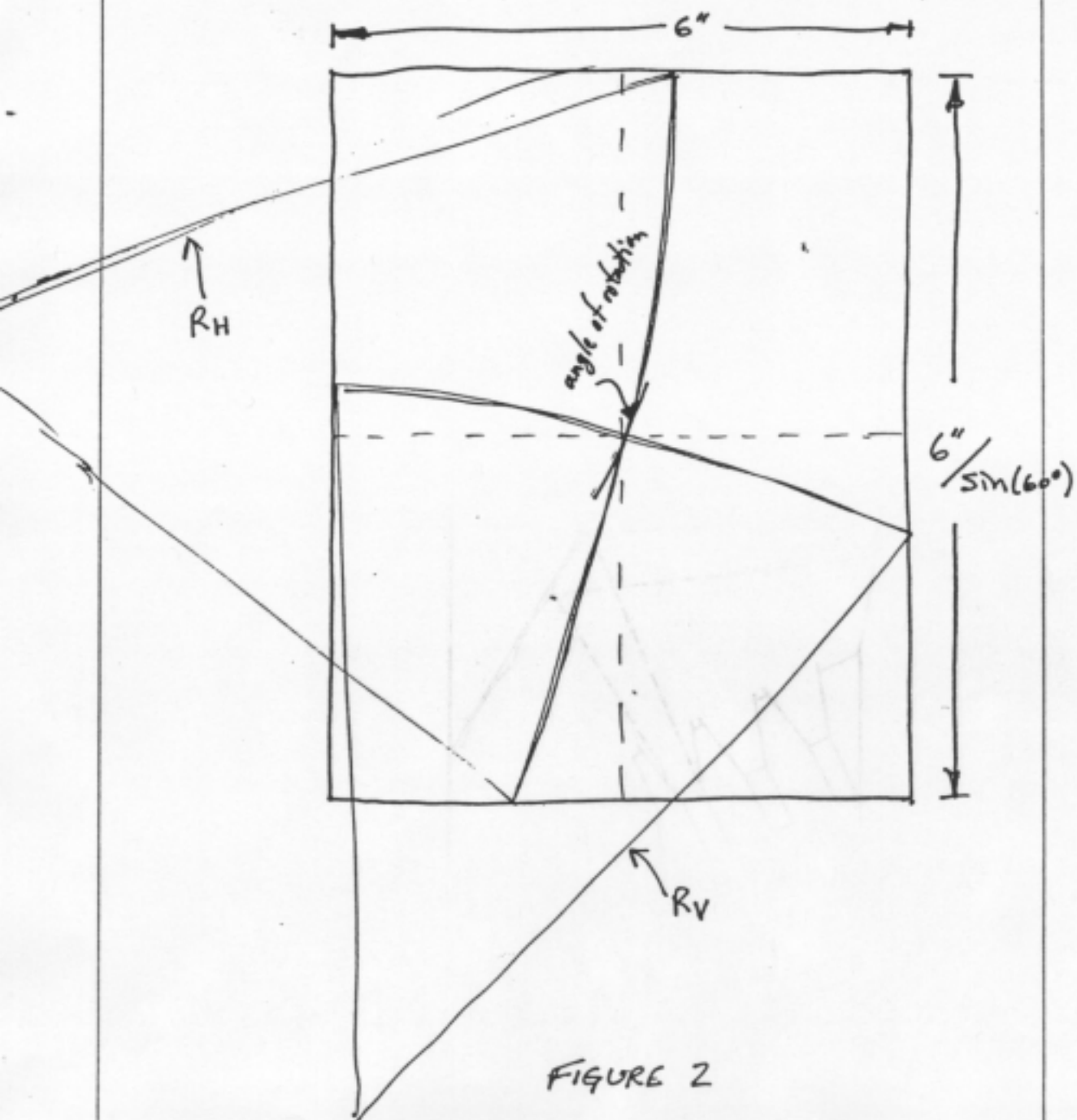angle of rotation

R_H

R_V

FIGURE 2

MIRROR TYPES

X's INDICATE DESIGN POSITIONS
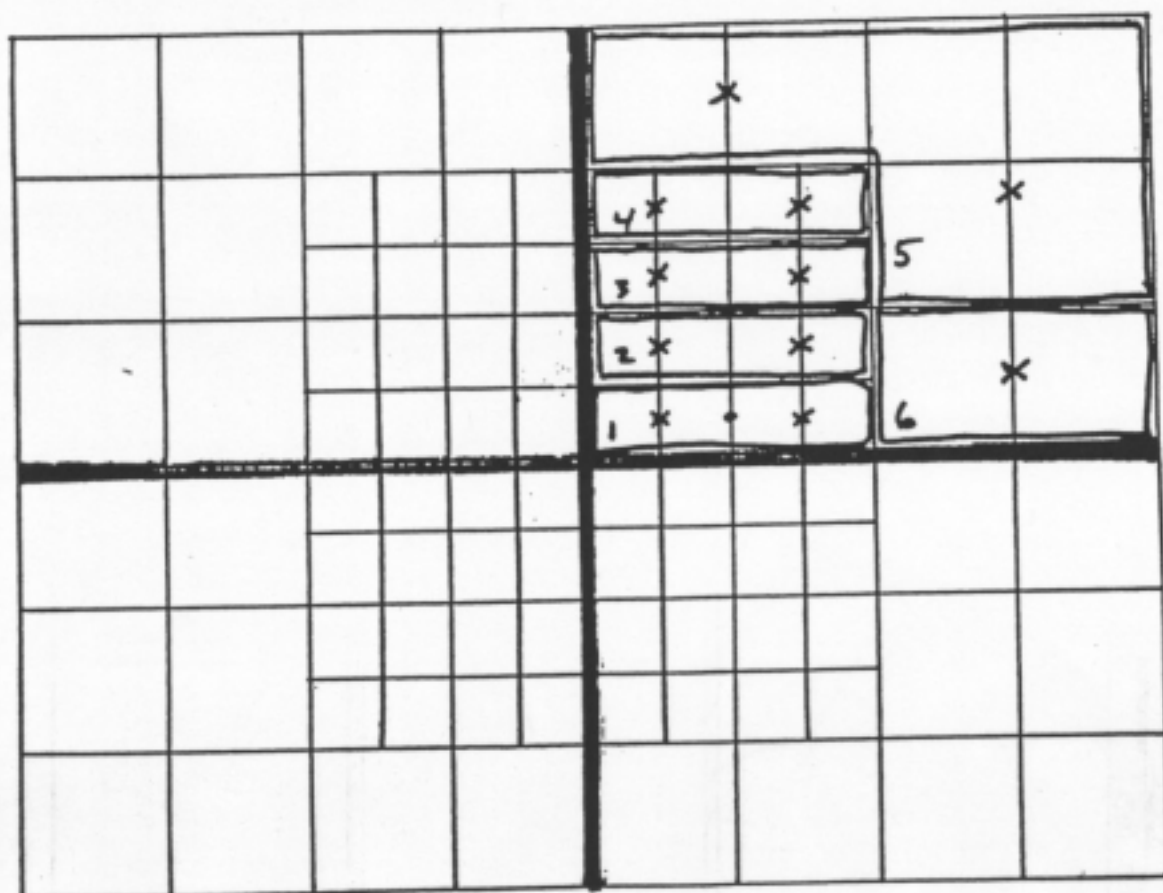
FIGURE 3

NATIONAL ACCELERATOR LABORATORY
ENGINEERING NOTE

SECTION	PROJECT	SERIAL - CATEGORY	PAGE

SUBJECT E690 Č₀ MIRROR PANNEL

NAME DCC
DATE 2/21/03

1" thick ⅛" cell 1.8 lb/ft³
Nomex core w/.005"-.006"
woven graphite skins

2" close-out

57"

30°

7°

VIEW A

A

2"+0
-¼"

Close-out

96"

2"+0
-¼"
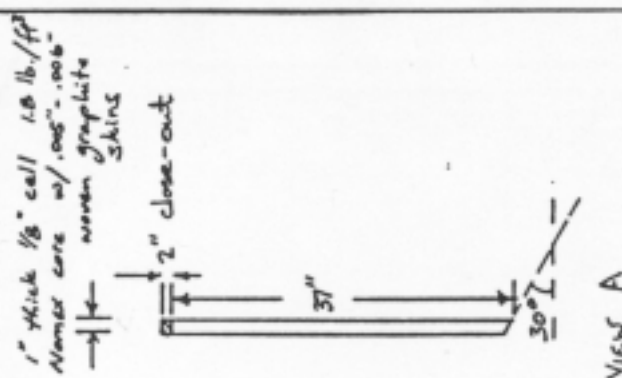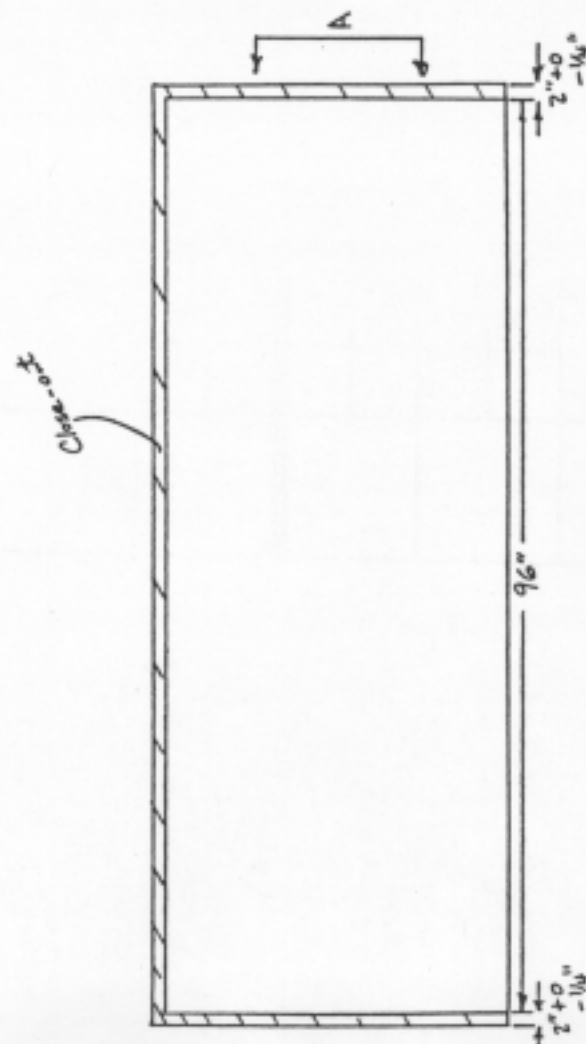
FIGURE 4

10/2/83

location of pannel & lights for mirror- gluing

"center of target."

edge of honeycomb.

109.245"

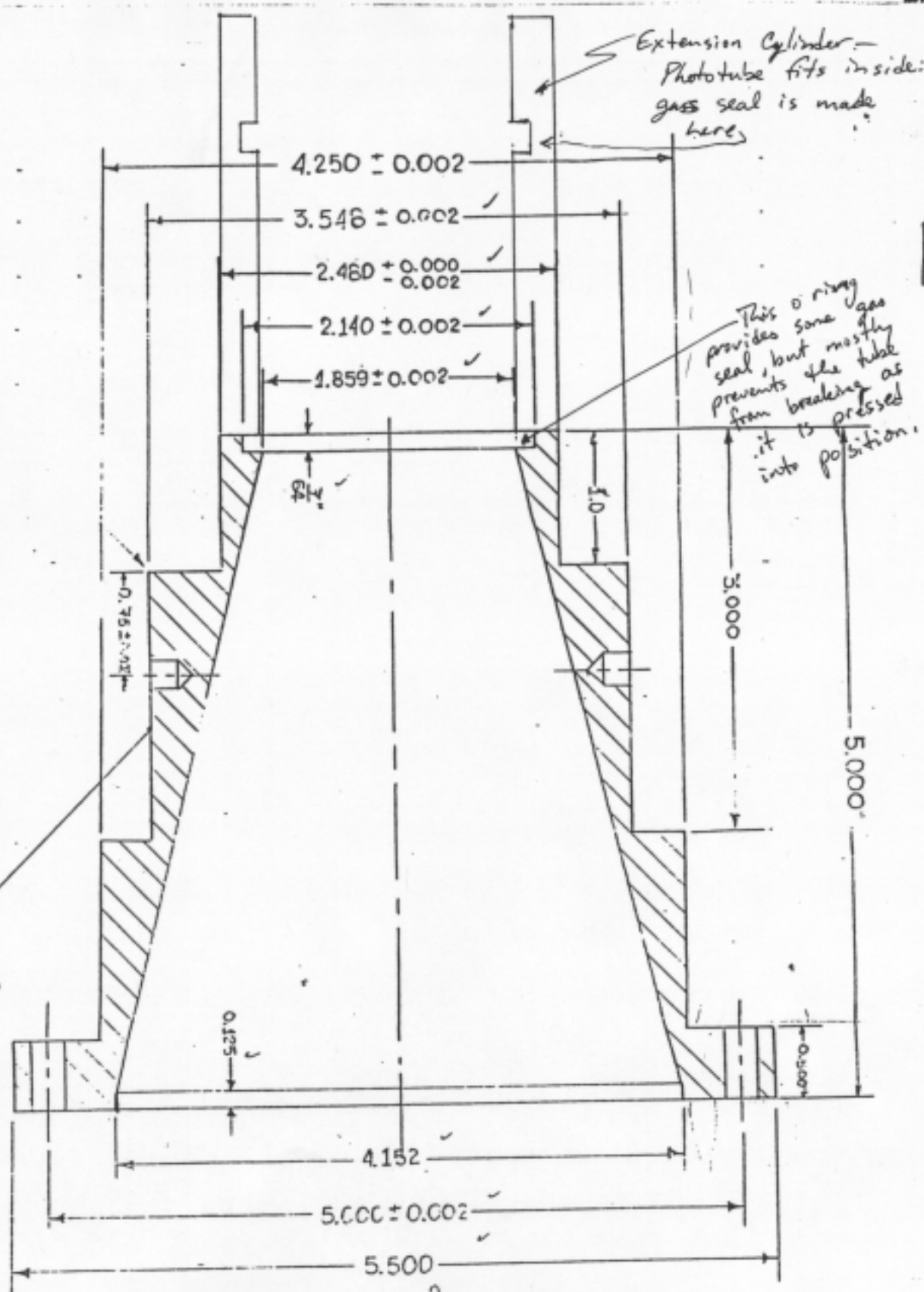14.06" ← 25.01"

|← 63.45" →|

level of top of honeycomb
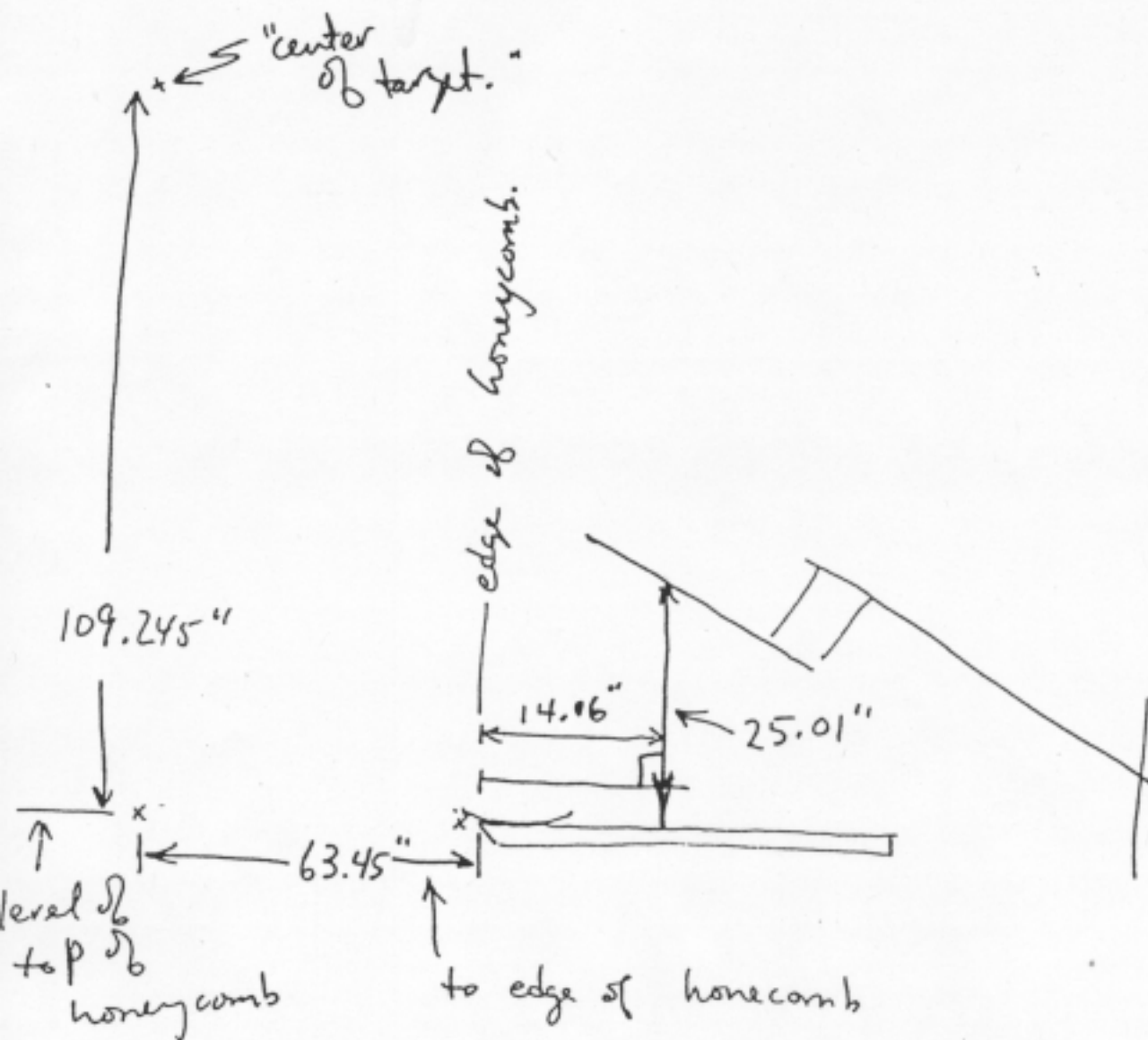
to edge of honecomb

Notes : 109.245" = 126.145" × cos (30°)

63.45 = 63.0725 + .38   (mirrors extend .38" pa edge of honeycomb

14.06" = 30" - 15.56" - .38"

FIGURE 5

Extension Cylinder—
Phototube fits inside;
gass seal is made
here.

4.250 ± 0.002

3.548 ± 0.002

2.460 + 0.000 − 0.002

2.140 ± 0.002

1.859 ± 0.002

This o'ring
provides some gas
seal, but mostly
prevents the tube
from breaking as
it is pressed
into position.

1.0

3.000

5.000

0.75 ± 0.01

Ajustar al diametro
interior del Tubo.
3/4" ⌀ num cedula 40.

2½" ⌀ - 20 NC
para ½" - @ 180°CN

0.125

4.152

5.000 ± 0.002

5.500

0.500

VER VISTA SUPERIOR
PLANO B.

PLANO A

Mirror "Row" 1

(Straight line is dispersion-free limit)

All Mirror "Rows"
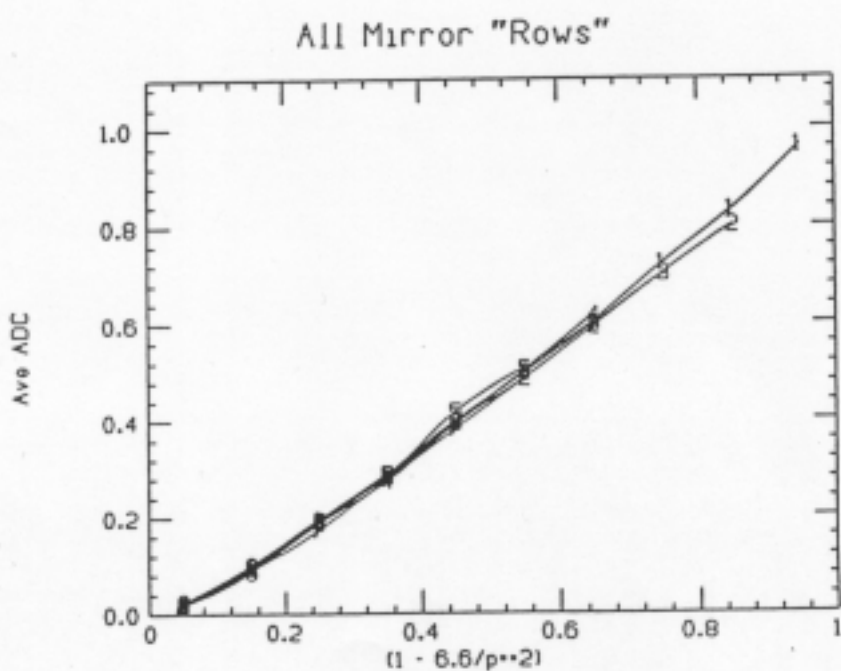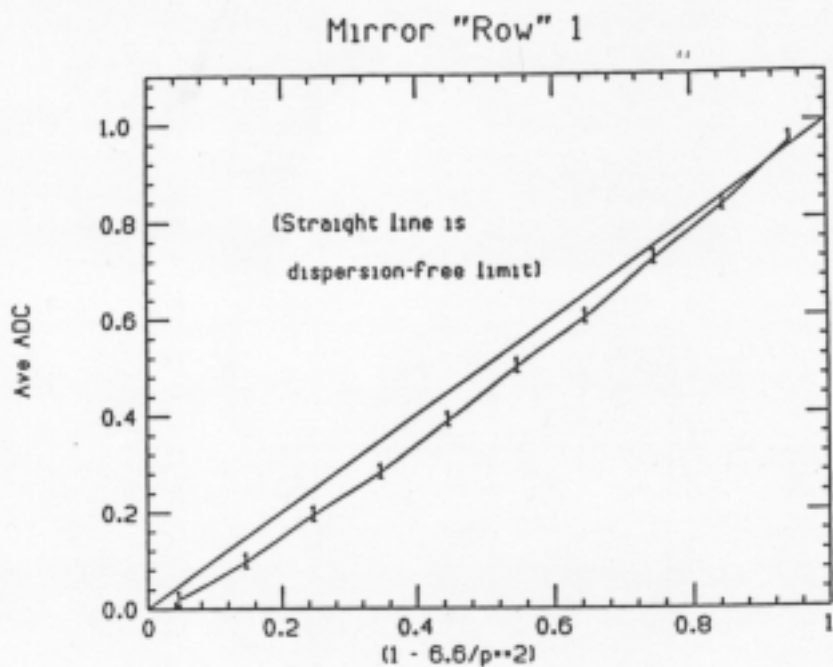
FIGURE 7

| 35 | 38 | 39 | 40 | 41 ⑦ | 42 | 45 | 48 |

34	⑥ 37	4	8	12	16	④ 20	24	28	32	⑥ 44	47
		3	7	11	15	③ 19	23	27	31		
33	⑤ 36	2	6	10	14	② 18	22	26	30	⑤ 43	46
		1	5	9	13	① 17	21	25	29		

81	84	49	53	57	61	65	69	73	77	91	94
		50	54	58	62	66	70	74	78		
82	85	51	55	59	63	67	71	75	79	92	95
		52	56	60	64	68	72	76	80		

| 83 | 86 | 87 | 88 | 89 | 90 | 93 | 96 |

MIRROR "ROWS" AND NUMBERING

— LOOKING DOWNSTREAM —

FIGURE 8